MPC-EX Physics Motivation: Transverse Spin

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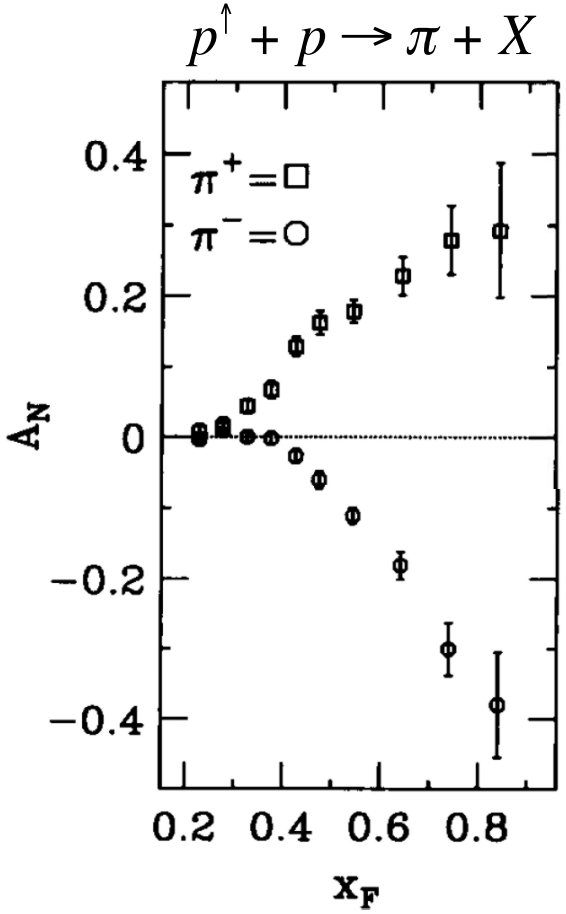
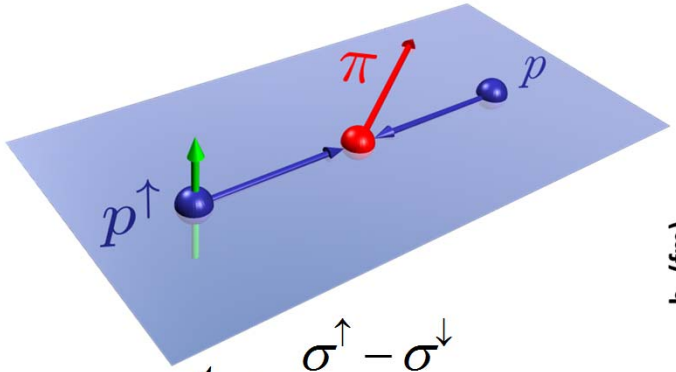
SSA's: Quarks can tell left-right in $p\,p^{\uparrow} \rightarrow \pi X$



FNAL-E704: PLB 264 (1991) 462.

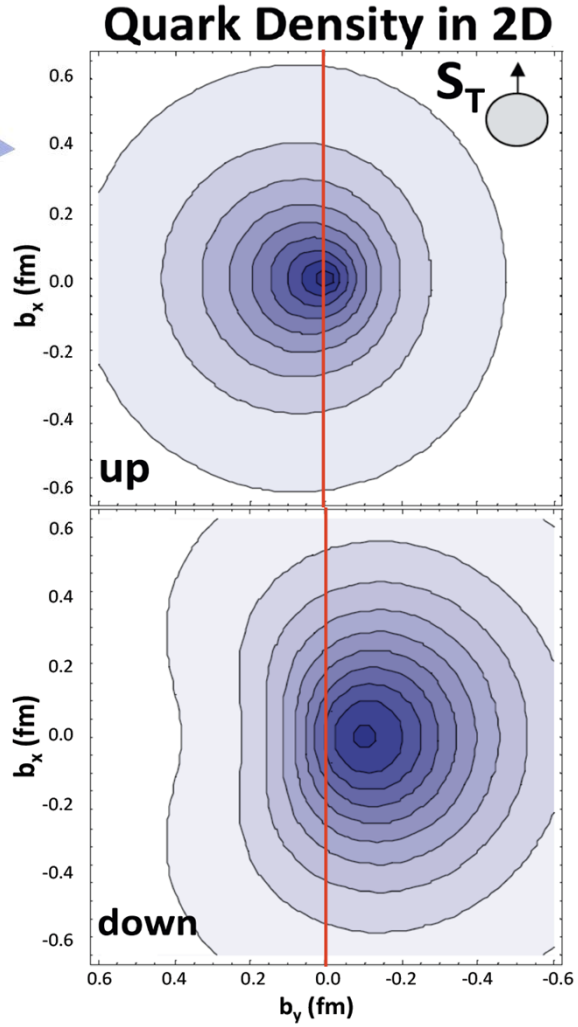


$$A_N = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}$$

$\pi^+ (u\bar{d})$ favors left

$\pi^- (d\bar{u})$ favors right

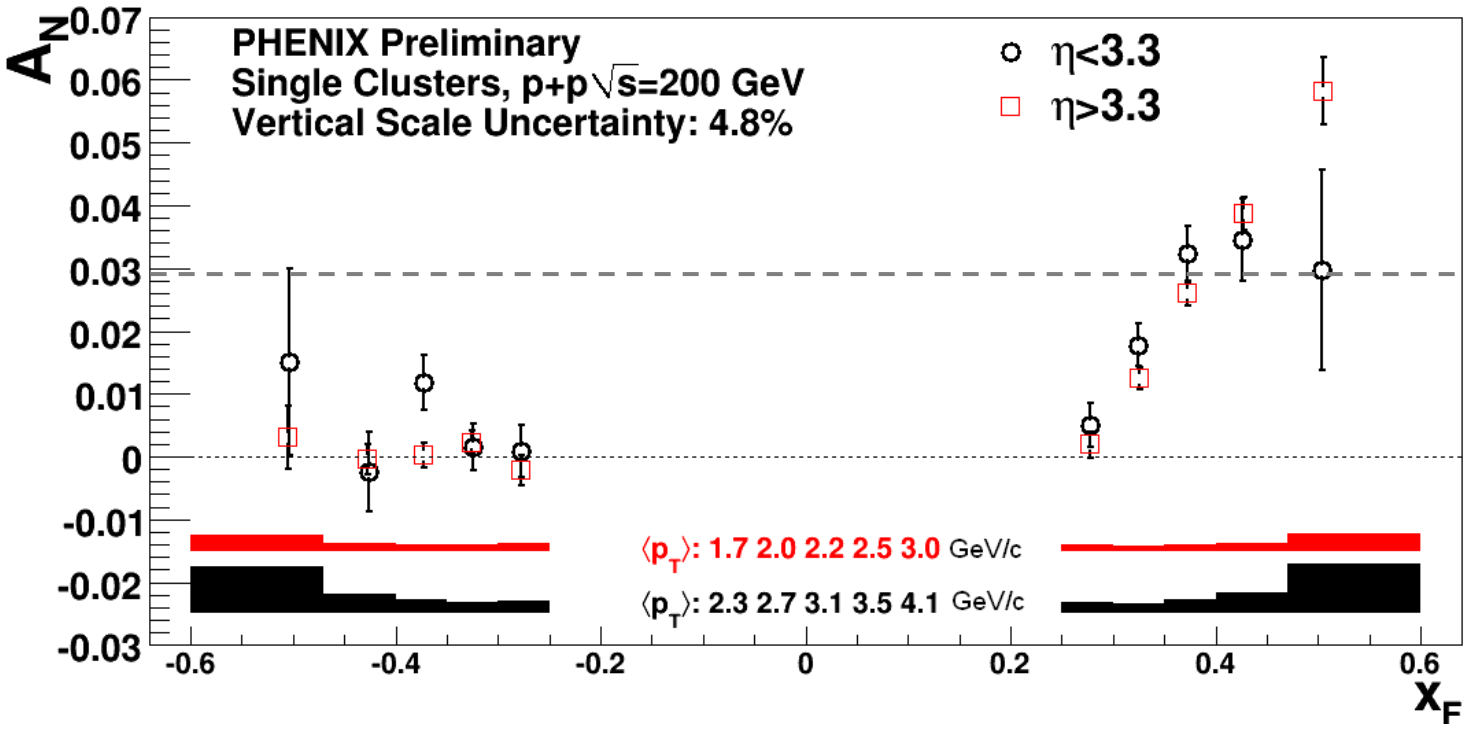
One possible explanation (Sivers effect): quark's transverse motion generates a left-right bias.



Lattice QCD PRL98:222001,2007.

up-quarks favor left (L_u>0), down-quarks favor right (L_d<0).

Cluster A_N in PHENIX

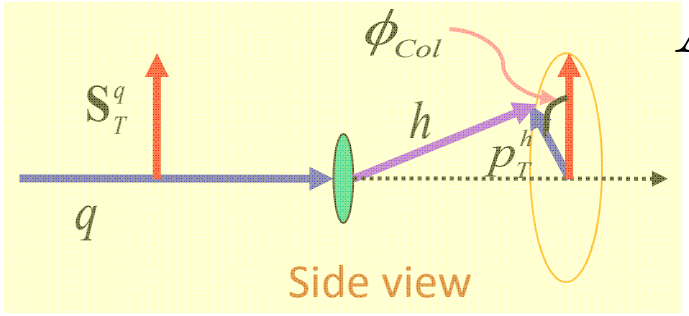


~3%

- STAR/PHENIX have measured large SSA's for neutral pions and eta mesons
- Current measurements cannot address the source of these asymmetries
  - Need more targeted measurements

How could a quark tell left from right ?

- Collins: a transversely polarized quark generates left-right asymmetry in the process of fragmentation.



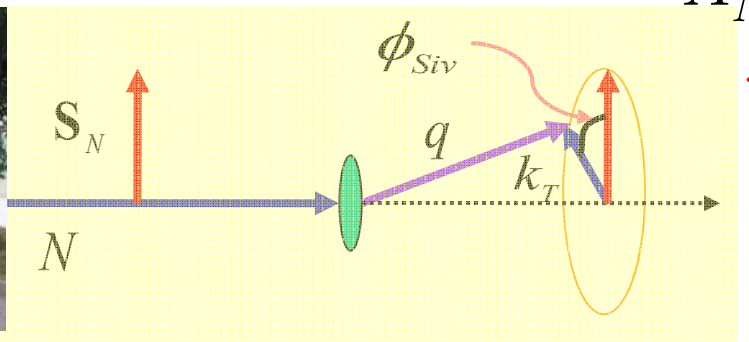
$$A_N^{Collins} \propto \delta q(x) \otimes H_{1q}^{\perp h}(z, P_{h\perp}^2)$$

Transversity: quark's transverse spin.

T-Odd fragmentation function

- Sivers: quark-distribution is left-right asymmetric in a transversely polarized nucleon due to quark's transverse motion.

$$A_N^{Sivers} \propto f_{1T}^{\perp q}(x) \otimes D_{1q}^{\perp h}(z, P_{h\perp}^2)$$

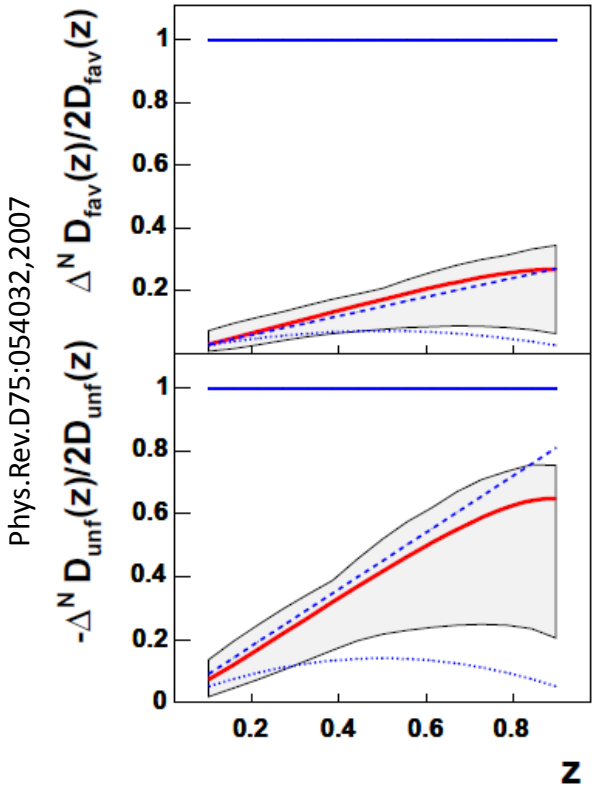


T-Odd quark distribution: Sivers distr.

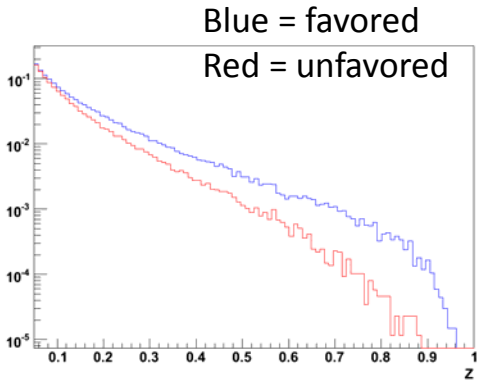
Regular fragmentation function

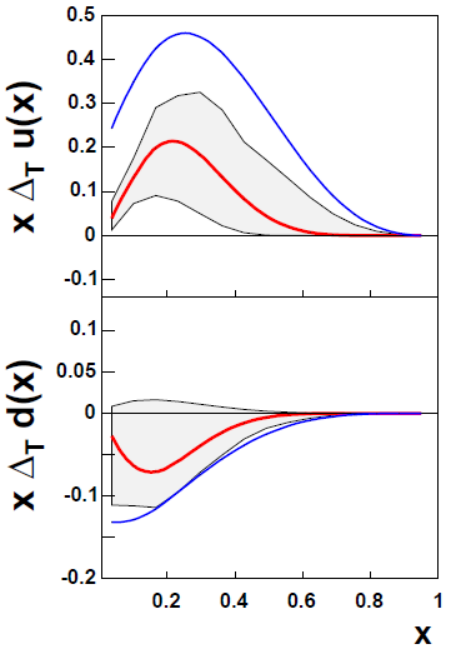
The toyMC Monte Carlo

- toyMC is a simple Monte Carlo that models polarized p+p interactions according to SIDIS extractions
  - Based on pythia for parton scattering
  - Spin information implemented following transversity
  - Implements Collins FF (spin-dependent fragmentation)

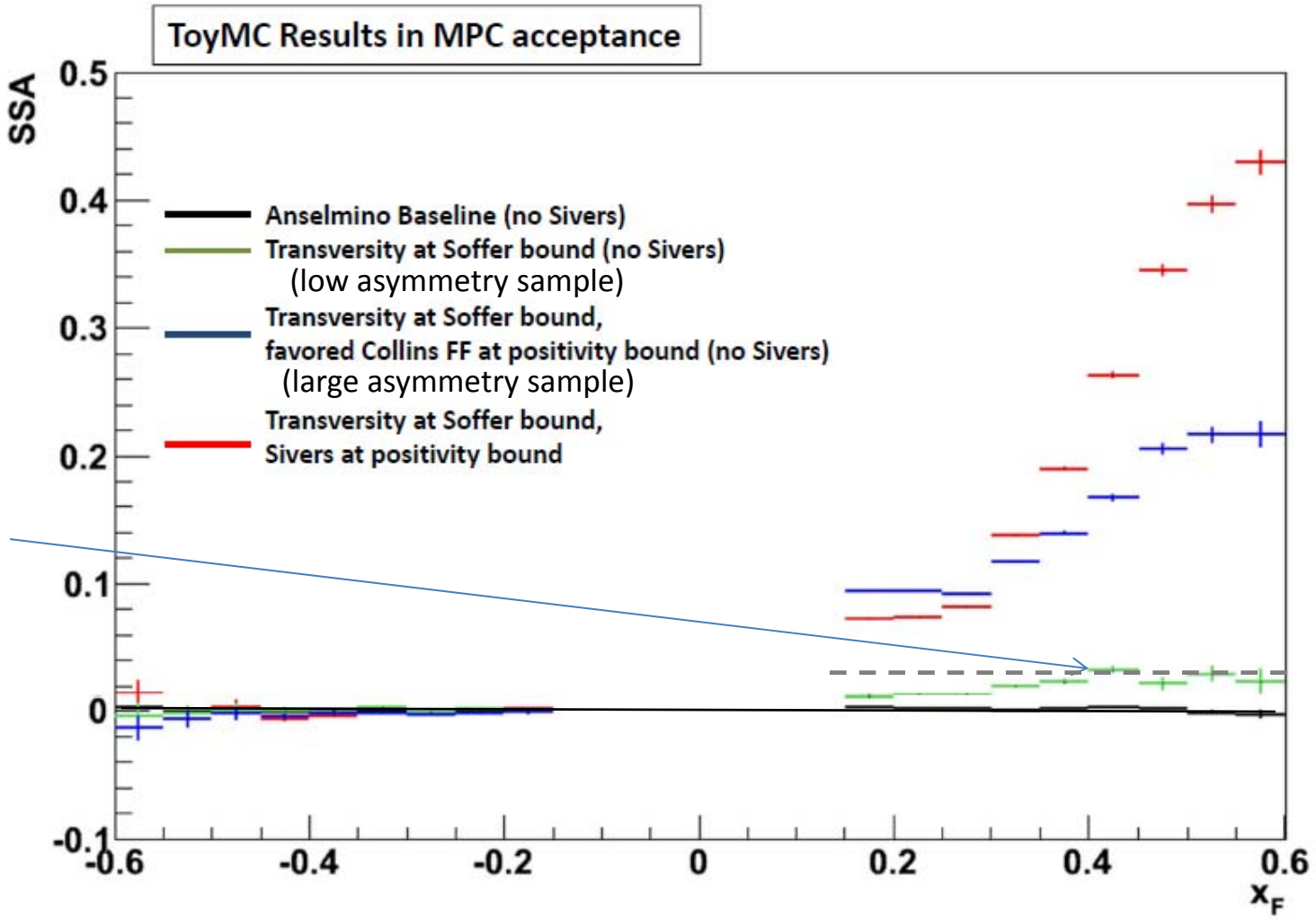


$$D_{h/q,s}(z,p_\perp) = D_{h/q}(z,p_\perp) + \frac{1}{2}\Delta^N D_{h/q\uparrow}(z,p_\perp)\ \ \hat{\mathbf{s}}\cdot(\hat{\mathbf{p}}_q \times \hat{\mathbf{p}}_\perp)$$



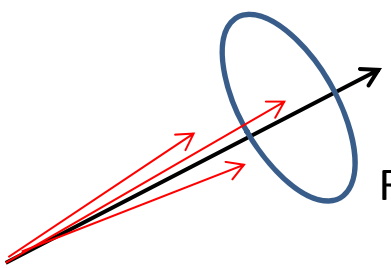


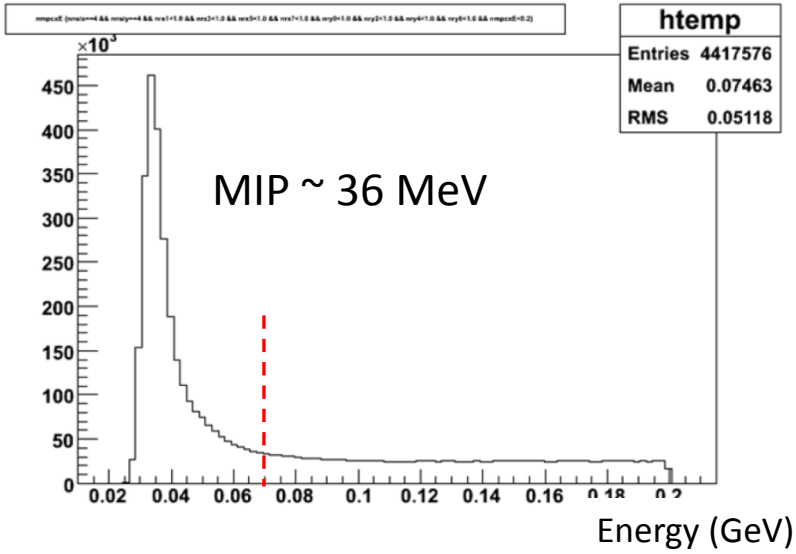
Single Particle π^0 A_N in Simulation



$A_N \sim 0.03$

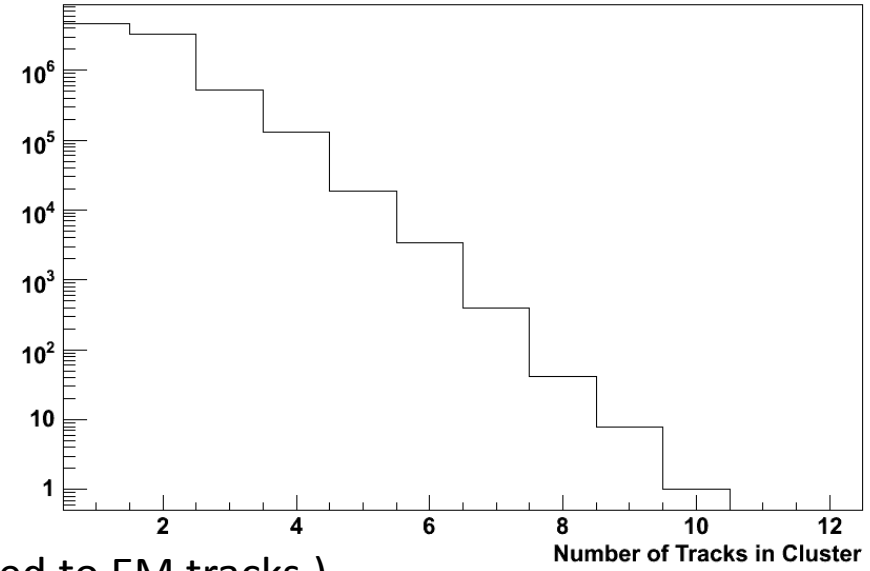
Charged Track/Cluster Reconstruction





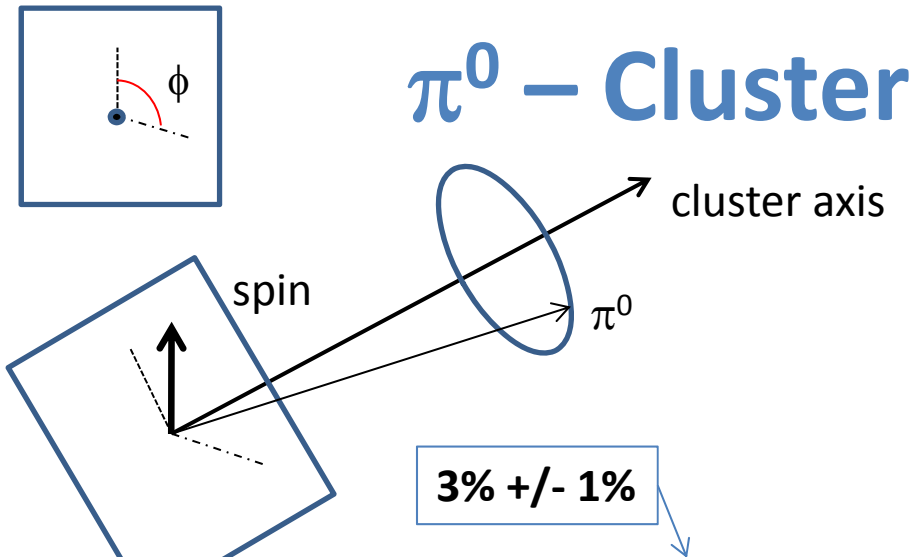
Charged Track Requirements:
- All layers in x, y hit
- Summed energy < 70 MeV

- All tracks used as seed
- For each seed iterated until stable
- Select the "highest p_T" cluster



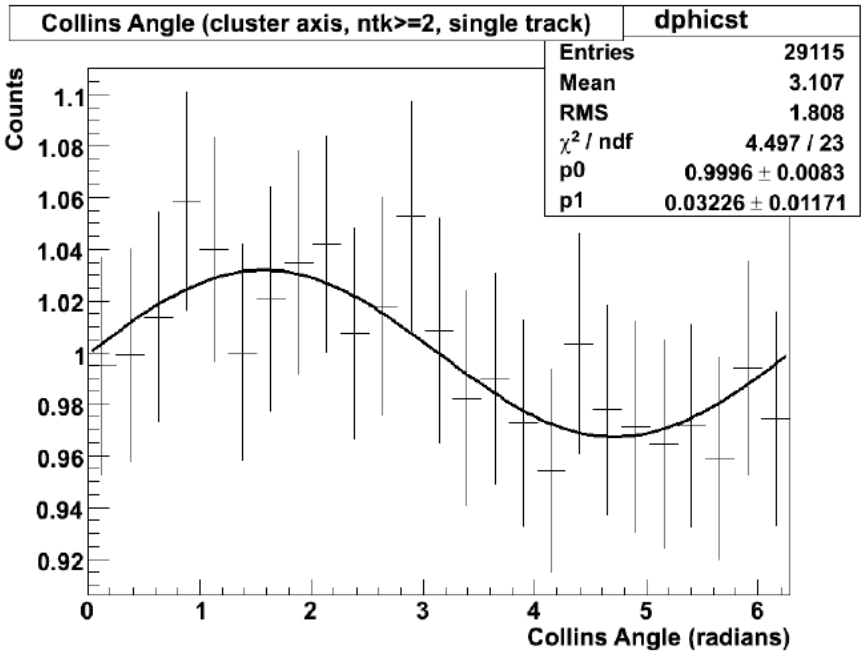
(Same reconstruction method can be applied to EM tracks.)

π^0 – Cluster Correlation

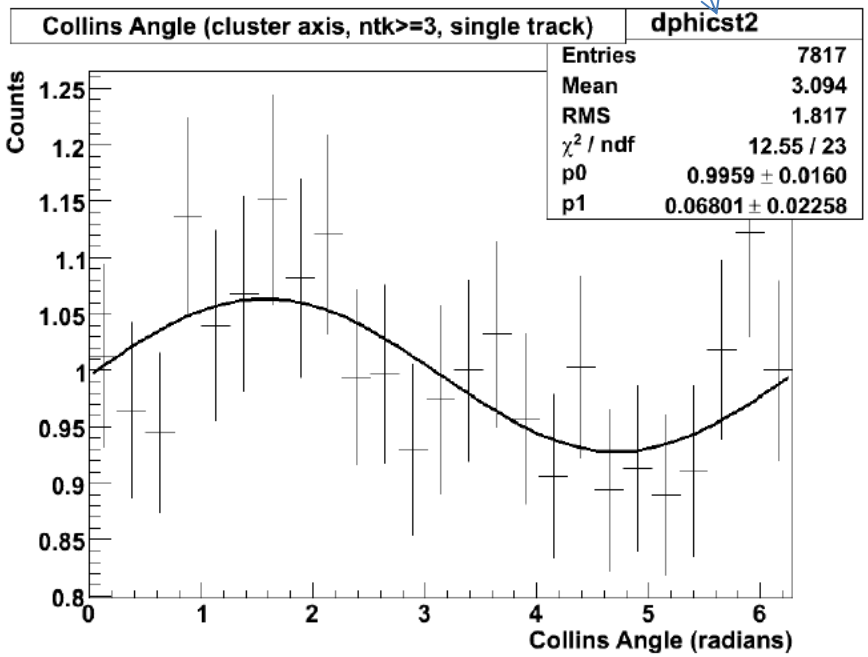


2 or **3** tracks in charged cluster
Correlations divided by spin-randomized distributions to account for acceptance.

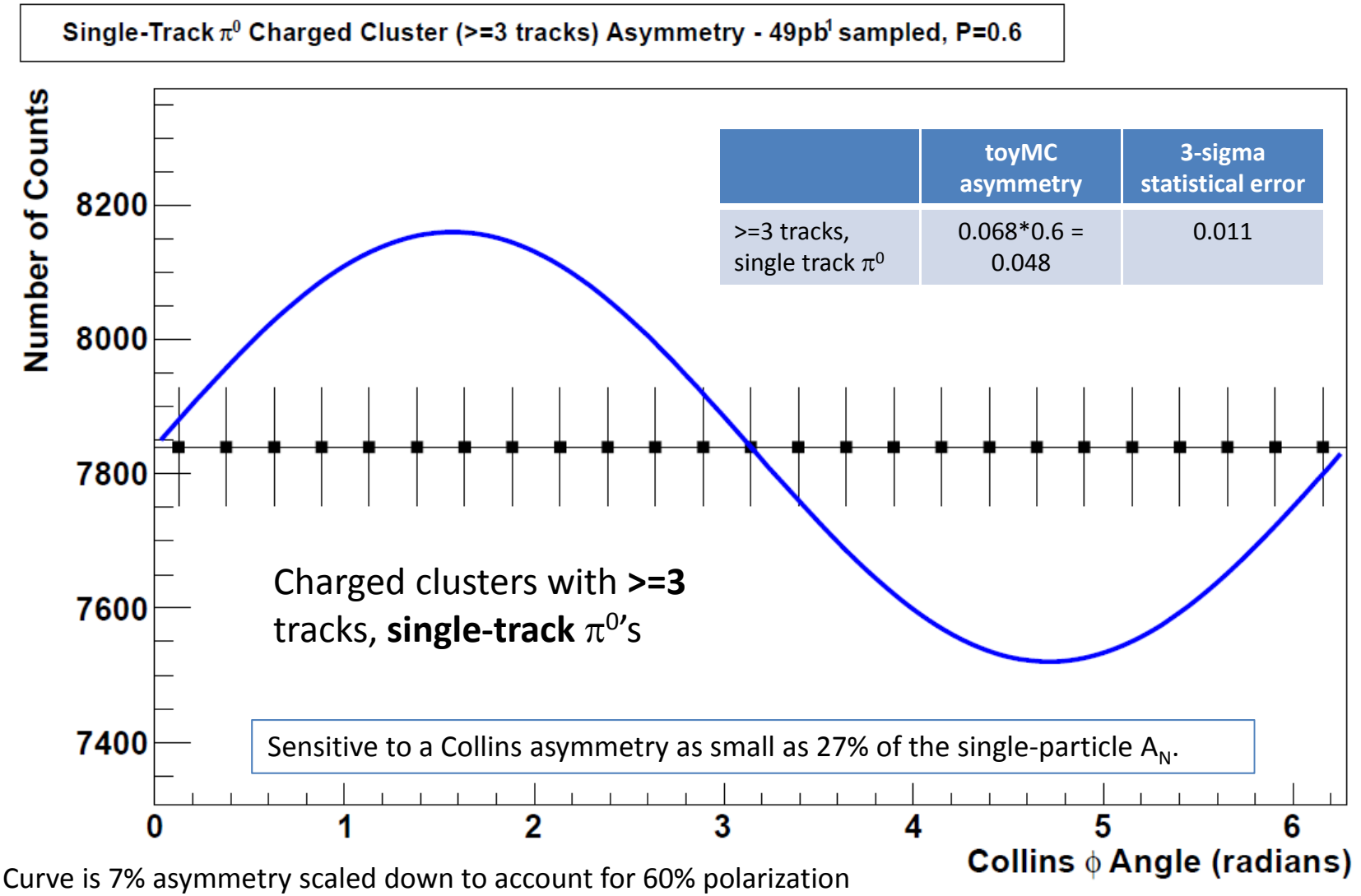
3% +/- 1%



7% +/- 2%

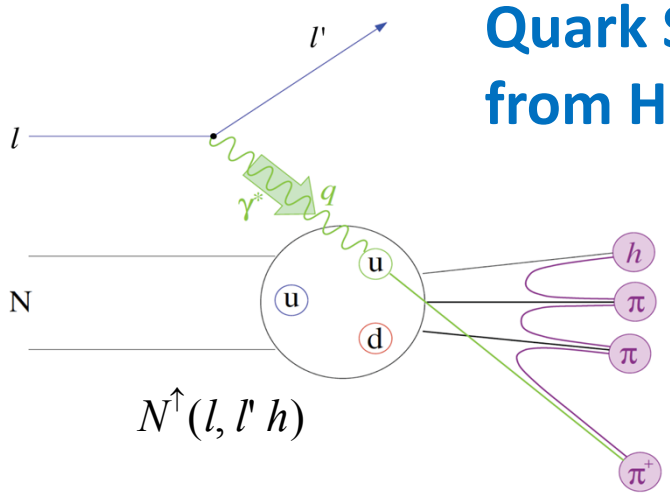


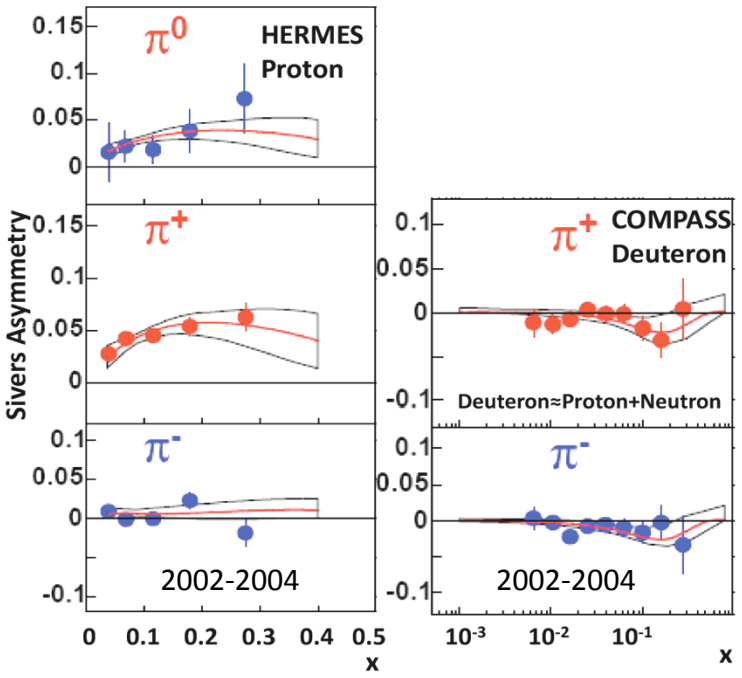
Collins in Jets Performance Plot

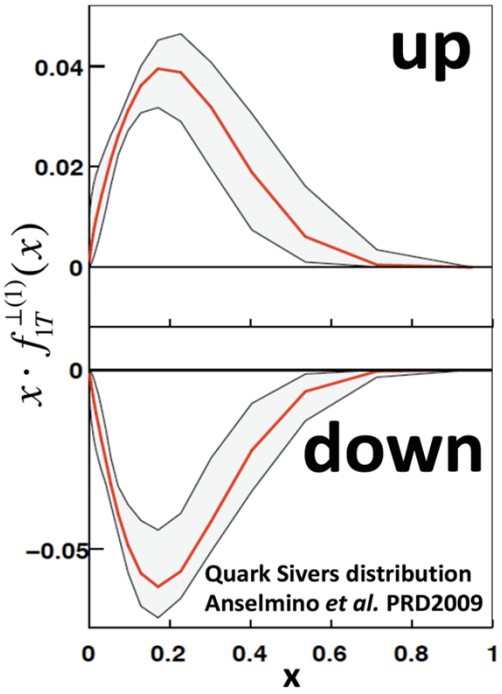


Curve is 7% asymmetry scaled down to account for 60% polarization

Quark Sivers distributions from HERMES Proton and COMPASS Deutron data







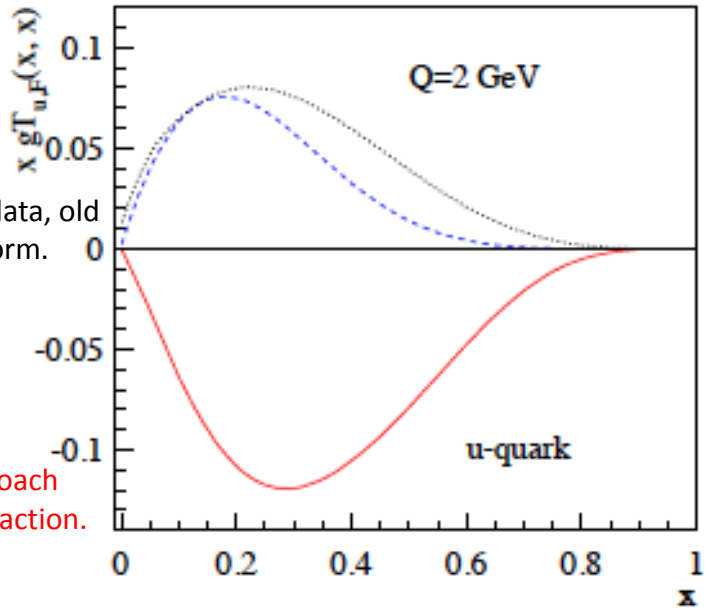
up-quarks favor left (L_u>0),

down-quarks favor right (L_d<0).

A Sign Mismatch of the Sivers function

Fit of SIDIS data, old functional form.

twist-3 approach "direct" extraction.



Fit of SIDIS data, new functional form.

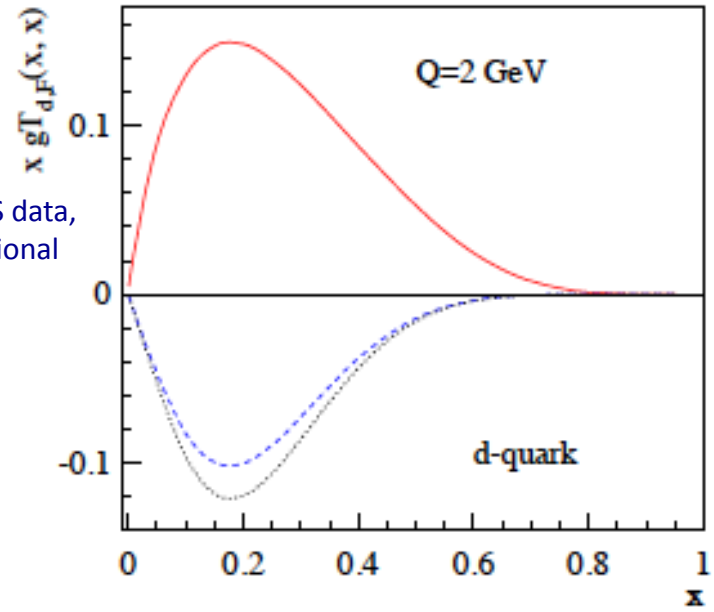
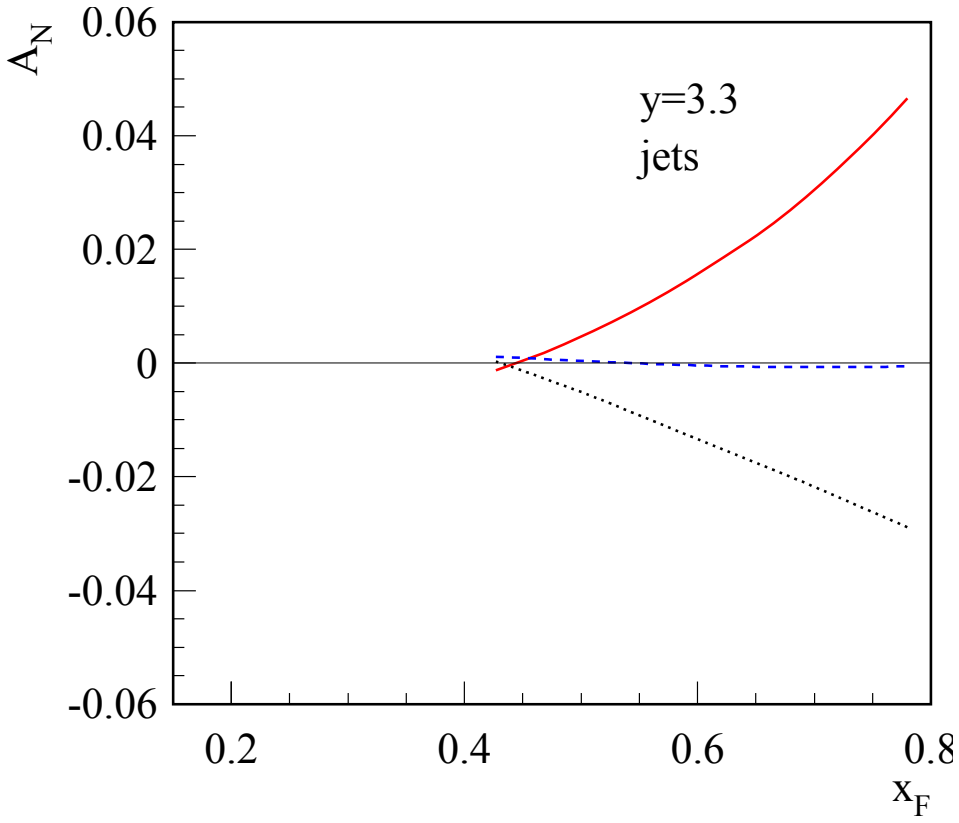


FIG. 1: The quark-gluon correlation function $gT_{q,F}(x,x)$ as a function of momentum fraction x for u-quarks (left) and d-quarks (right). The dashed (dotted) lines are $gT_{q,F}(x,x)|_{\text{new Sivers}}$ ($gT_{q,F}(x,x)|_{\text{old Sivers}}$) obtained by taking the $k_\perp$-moments of the corresponding quark Sivers functions according to the right-hand-side of Eq. (10). The solid lines represent the correlation functions extracted directly from data on SSAs for inclusive pion production in proton-proton collisions, $p^\uparrow p \to \pi + X$ [14], after correcting for the sign convention (see text).

Collinear twist-3 method in analyzing p+p data yields opposite signs of quark Sivers function moments compared to that from Semi-Inclusive Deep-Inelastic Scattering.

200 GeV p+p Jet A_N



twist-3 approach "direct" extraction.

Fit of SIDIS data, new functional form.

Fit of SIDIS data, old functional form.

Zhong-Bo Kang et al. arXiv:1103.1591

A very straightforward measurement for the MPC-EX.

Conclusions

- **The MPC-EX can address key issues in the study of transverse SSA's in polarized p+p collisions at RHIC:**
  - Is the origin of these SSA's in the initial or final state?
    - Deeper insight into nucleon structure
  - How large are factorization breaking effects?
    - How can we compare DIS and p+p results?
  - What is the correct approach in pQCD?
    - Importance of collinear factorization approach, twist-3, and final-state corrections

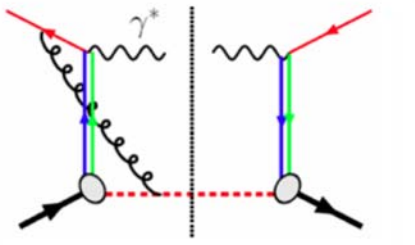
BACKUP

Quark Sivers Distribution

Forbidden before 2002 quark Sivers distribution

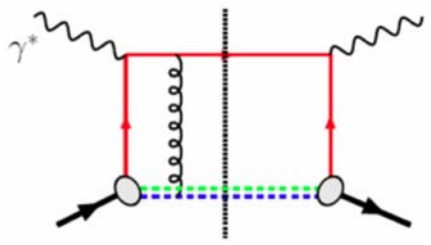
- Naive T-odd, not allowed for collinear quarks. Transverse Mom. Dep. parton distributions (TMDs).
- Correlation between nucleon spin and quark's transverse momentum.
- Imaginary piece of interference $L_q=0$ ✖ $L_q=1$ quark wave functions.
- Gauge invariance of QCD requires Sivers function to flip sign between semi-inclusive DIS and Drell-Yan.

$$f_{1T}^{\perp q}\Big|_{SIDIS} = -f_{1T}^{\perp q}\Big|_{D-Y}$$



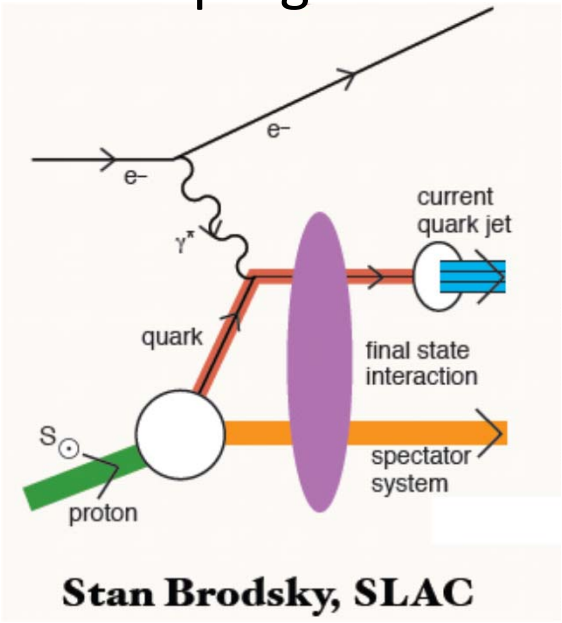
$p^{\uparrow} + p \to [\gamma^* \to \ell^+\ell^-] + X$

DY: repulsive



$\ell + p^{\uparrow} \to \ell + \pi + X$

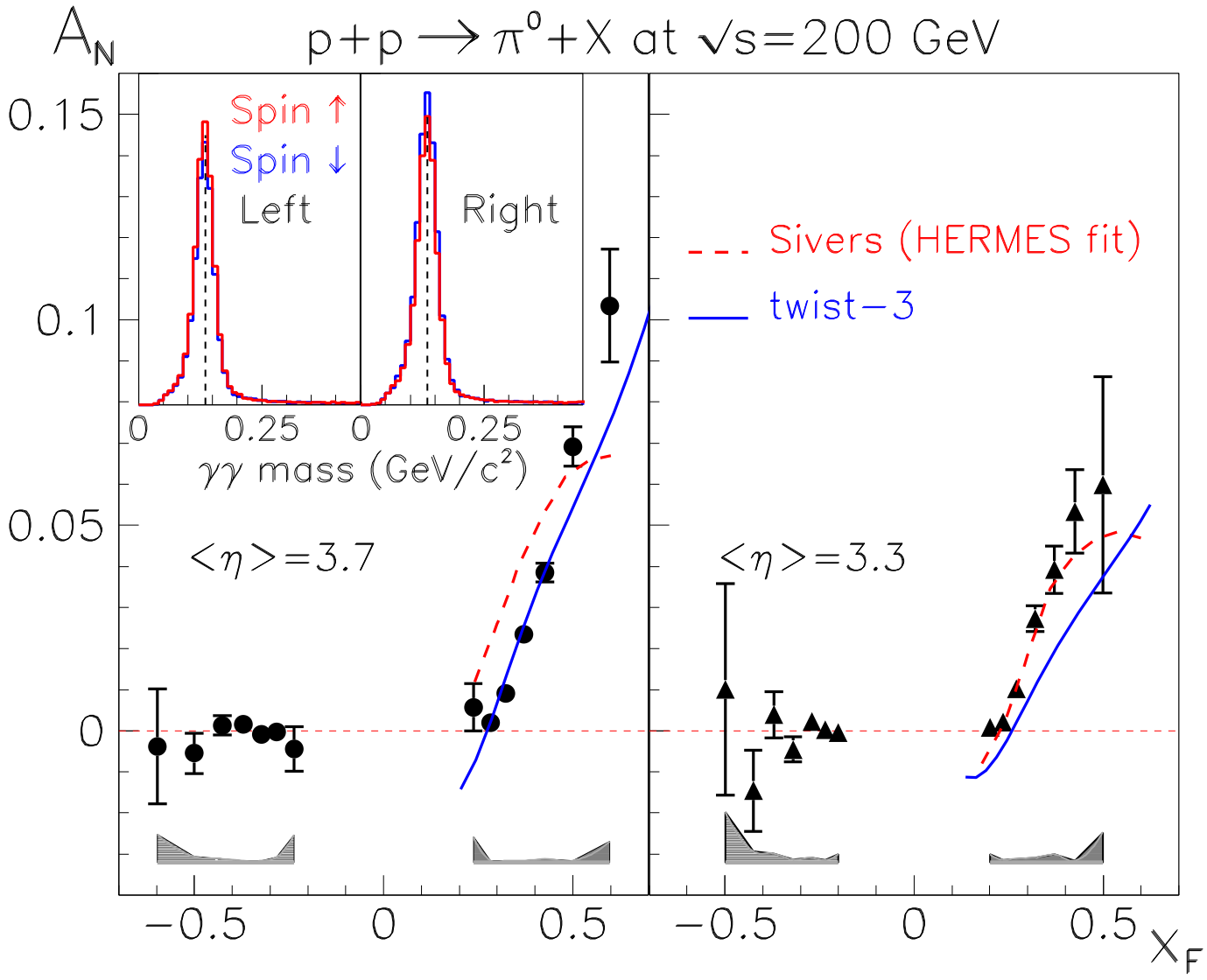
SIDIS: attractive



Stan Brodsky, SLAC

Final-State-Interaction

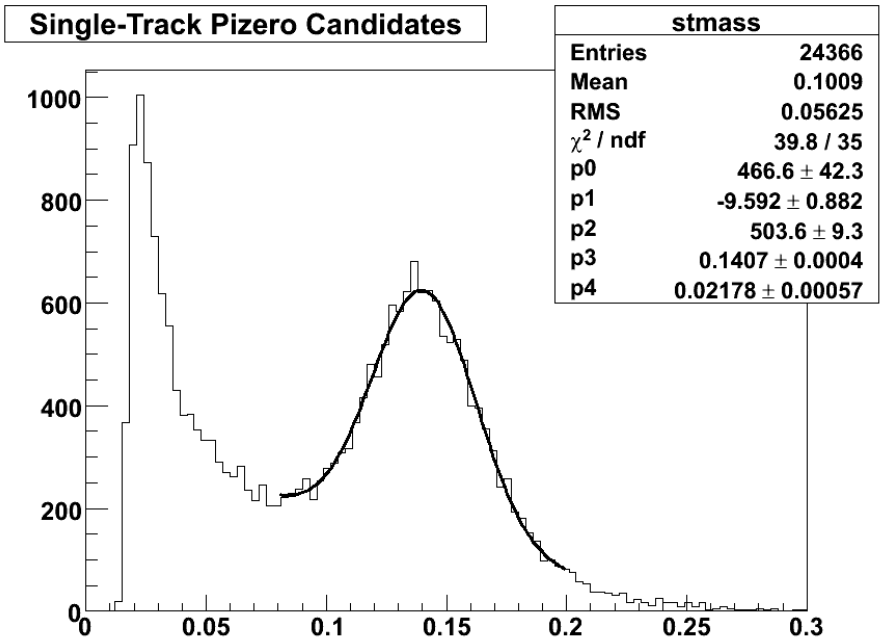
Large SSA observed in forward direction: STAR π^0



π^0 Reconstruction

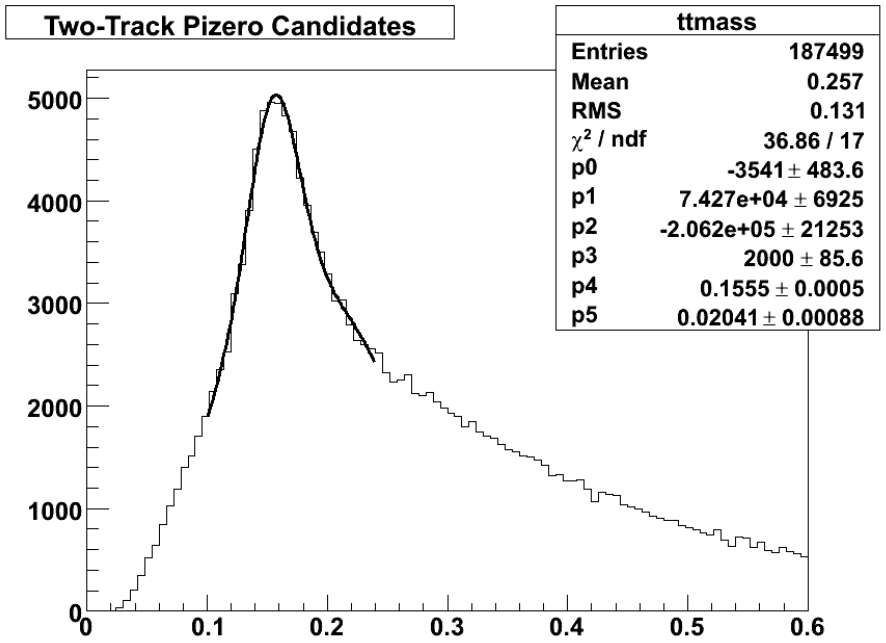
Selection of π^0's in jet events.

Single-track π^0's
E>20GeV



Less π^0's, less background…

Double-track π^0's
E>20GeV (each cluster)



More π^0's, more background…

Asymmetry Sensitivity

- To see a very small asymmetry, likely you would not bin in ϕ but use "sqrt method"

$$A_N{}^{raw} = \frac{\sqrt{N_L{}^{\uparrow} N_R{}^{\downarrow}} - \sqrt{N_L{}^{\downarrow} N_R{}^{\uparrow}}}{\sqrt{N_L{}^{\uparrow} N_R{}^{\downarrow}} + \sqrt{N_L{}^{\downarrow} N_R{}^{\uparrow}}}$$

  - Kind of like making two bins in ϕ (left/right)

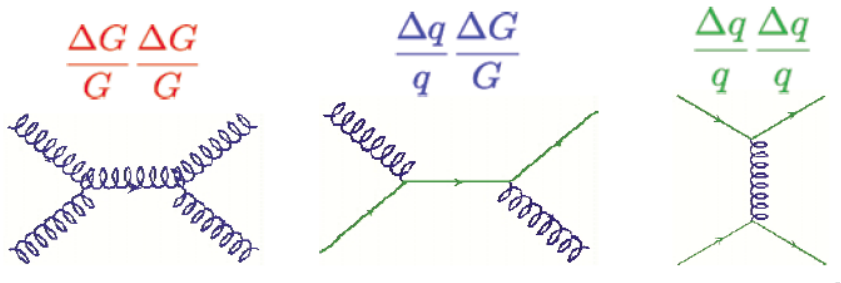
Can see a Collins asymmetry as small as 27% of the single-particle A_N.

	toyMC asymmetry	3-sigma statistical error
>=3 tracks, single track π^0	0.019*0.6 = 0.011	0.014
>=3 tracks, single track π^0	0.068*0.6 = 0.048	0.011

Other Spin topics: A_{LL} of Inclusive Jet

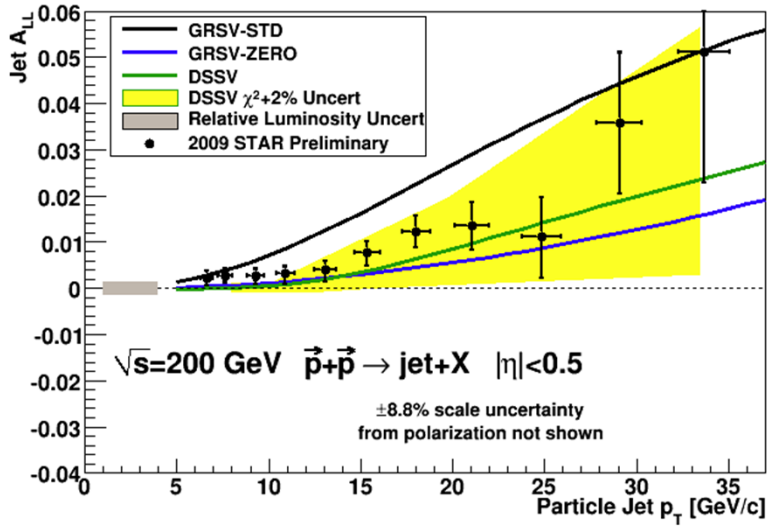
$$A_{LL} = \frac{\sigma^{++} - \sigma^{+-}}{\sigma^{++} + \sigma^{+-}} \propto \frac{\Delta f_a \Delta f_b}{f_a f_b} \hat{a}_{LL}$$

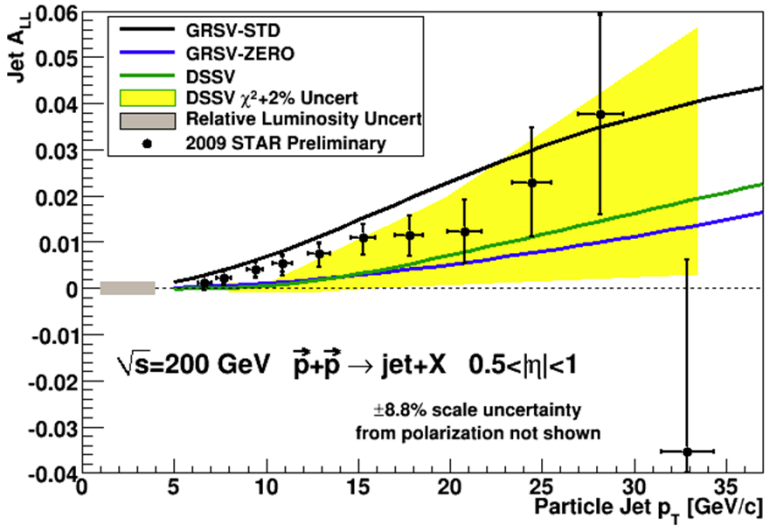
Δf: polarized parton distribution functions



$\Delta u(x_1)$ is well-known.
A_{LL} of forward jet can provide access to $\Delta G(x_2)$.

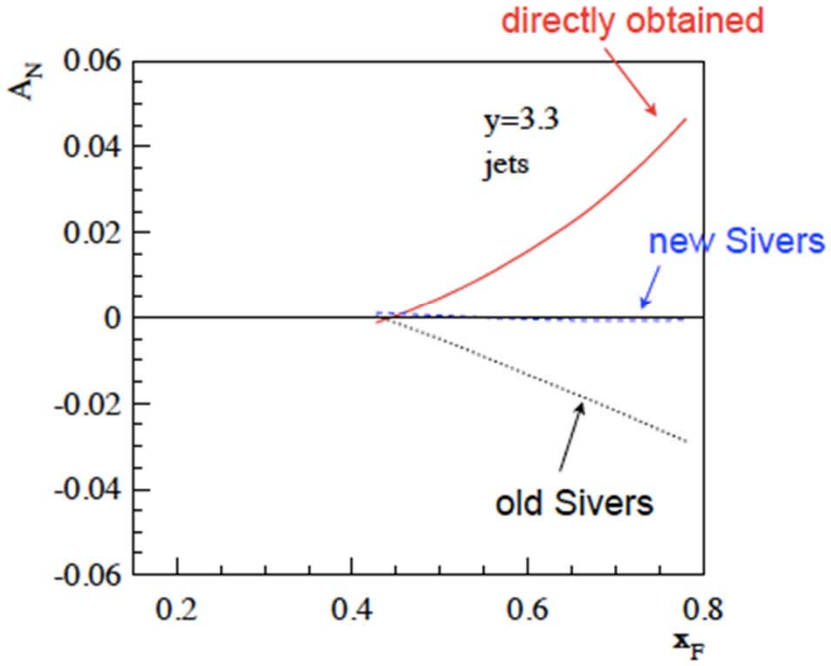
STAR Preliminary Results:

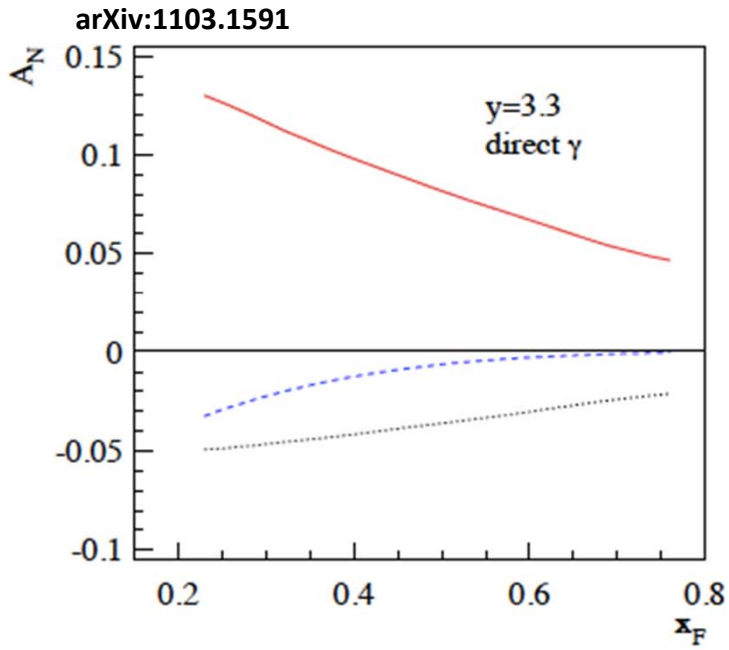




200 GeV p+p Single Spin Asymmetry of Jet and Direct Photon

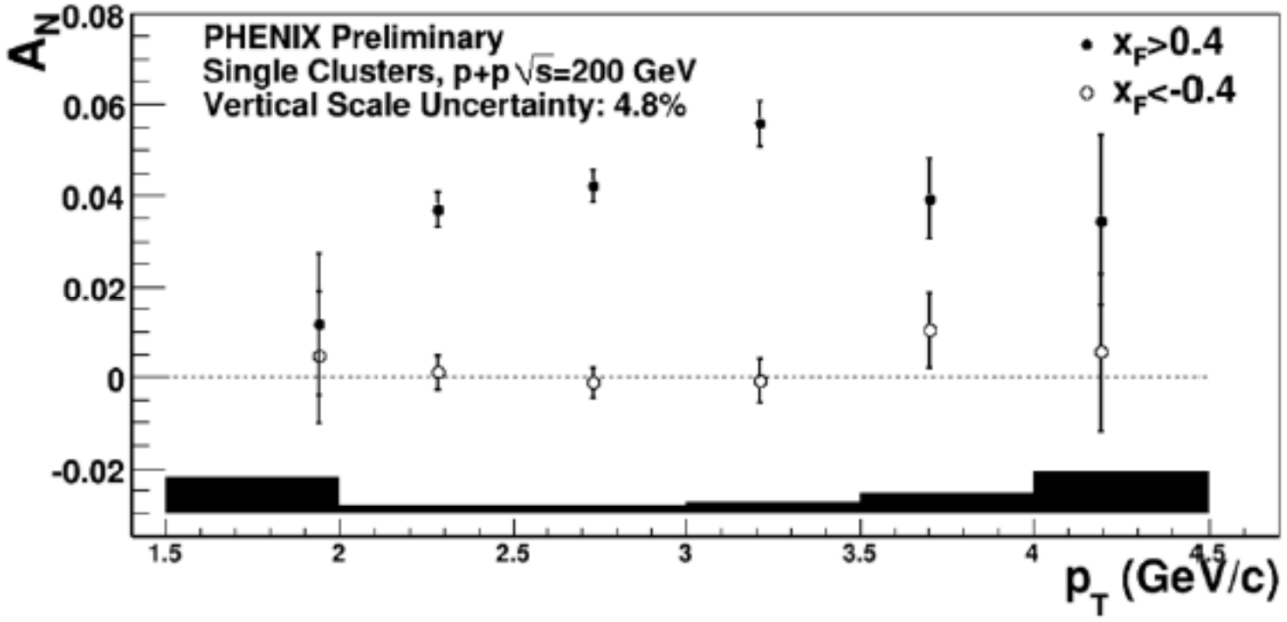
Zhong-Bo Kang et al.





MPC-EX can provide a clear answer to help resolving the puzzle on quark Sivers distribution.

Large SSA also observed in PHENIX: MPC Single Clusters

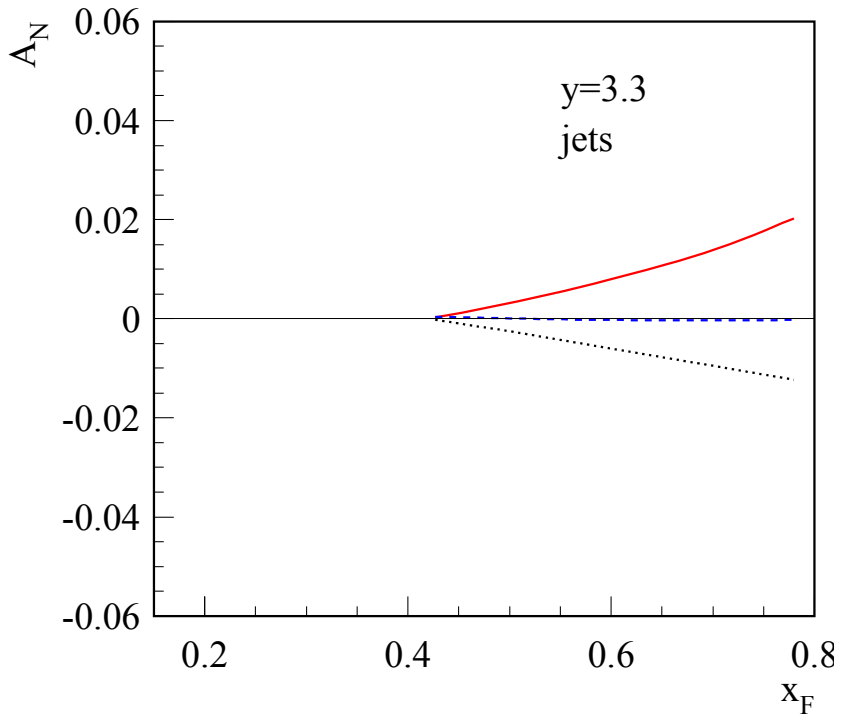


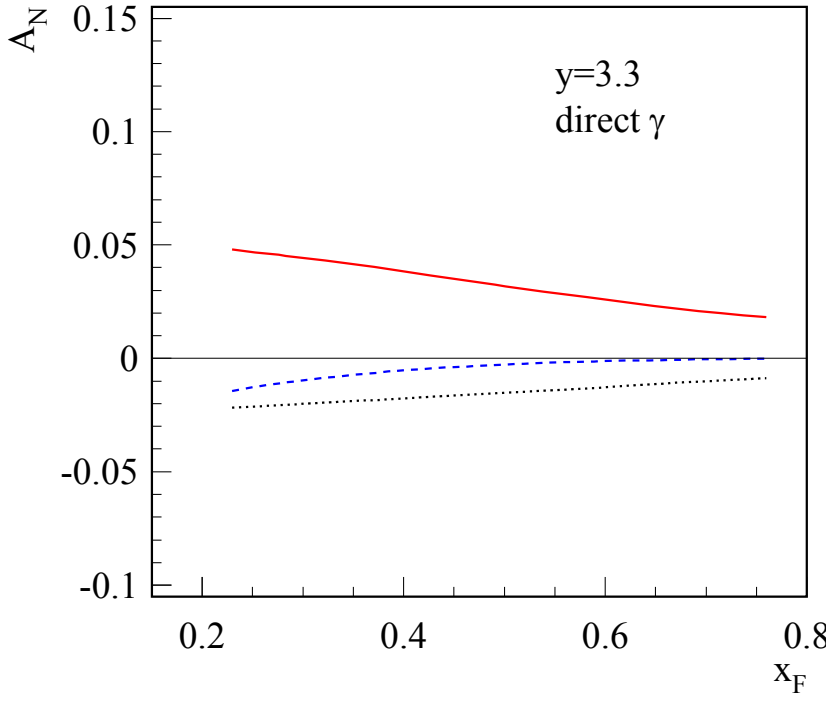
However, two mechanisms can not be distinguished in A_N of inclusive hadron production in p+p:

Collins effect: quark transverse spin (transversity) generates a left-right bias through fragmentation.

Sivers effect: quark transverse motion generates a left-right bias.

500 GeV p+p


A_N
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
0.2
0.4
0.6
0.8
x_F
y=3.3
jets


A_N
0.15
0.1
0.05
0
-0.05
-0.1
0.2
0.4
0.6
0.8
x_F
y=3.3
direct γ

SSA grows with p_t: STAR π^0